Measurement of ionization distributions at nanometre level in tissue-equivalent gas*

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Abstract The developed track detector consists of two parts: a small drift region to obtain a good tracking and a relatively large multiplication region for getting an enough high gain at low pressure. All the track detector can be moved in the direction perpendicular to the beam by means of a micrometric screw. An automatic system allows the counting gas to flow continuously at constant pressure through the detector during the measurements. The system can measure ionization distributions at a few nanometer range.
Keywords Ionization distributions, Nanometre level, Radiobiological effects

1 Introduction

The determination of energy-absorption patterns produced by the passage of ionizing particles in biological material is one of the basic tasks of microdosimetry. It is generally believed that the effects of radiation are primarily determined by what happens in individual small volumes, for example cell nuclei, chromosomes and cell membranes. Such sites are so small that the number of interactions between the biological molecules and charged particles is small. So, the knowledge of the ionization distributions at nanometre level is important because the DNA molecule has linear dimensions of this order of magnitude. It is particularly relevant to obtain information near the track core of charged particles because the majority of the radiobiological effects takes place due to high energy density released into this region. However, the accuracies of the calculation and experiments are limited by the availability of the electron-atom interaction cross sections and by the smallest feasible volume, respectively.

In order to finalize the issue one needs new instruments or techniques which can reveal the ionization track structure in detail. Therefore we took the experience of Colautti[1,2] and manufactured a promising track detector made up of two parts: a small drift region to obtain a good tracking and a relatively large multiplication region to get an enough high gain at low pressure. All the track detector can be moved in the direction perpendicular to the beam by means of a micrometric screw, so the distance between the particle track and the slit can be determined with a precision of better than 0.01 mm. The whole detection system is put in a chamber filled with the counting gas at the proper pressure. An automatic system allows the gas to flow continuously at constant pressure through the detector during the measurements. The detection system can recognize ionization distributions at a few nanometer range where radiation ionizations take place.

2 Experimental set-up

The experimental set-up is shown in Fig.1

2.1 Detector

The track detector is shown in Fig.2. A stainless steel block has been drilled to obtain a cylindrical cavity of 20.4 mm in diameter, two cylindrical guard tubes (ϕ1.8 mm$\times$10 mm) define the 25 mm long proportional counter; an anode wire of 10μm in diameter was used in theses measurements. The proportional counter is tangent to the lower side of the block in which a 25 mm long, 1 mm large and 0.5 mm thick slit has been milled. Through the slit the multiplication region communicates with the drift region which is 4 mm deep, behind this there is a well 30 mm deep to trap the scattered electron, an electroformed mesh of copper with 45 wires per inch and 88% of transparence closes

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the well and defines the lower side of the diffusion region; an identical mesh is attached on the upper side in order to prevent the electrical field distortions due to slit. The mesh in the lower side of the diffusion region can be removed and substituted with another plate to evaluate the influence of the boundaries on the electron backscattering. The region of producing pulses is defined by projection of the slit into the drift region. Then the sensitive volume, from which charges can drift into the multiplier, is therefore 1 mm×4 mm×25 mm.

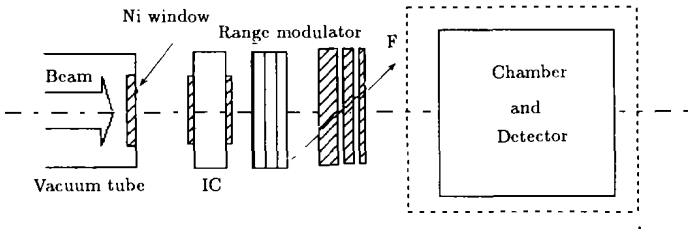

Fig.1 Schematic of experimental arrangement

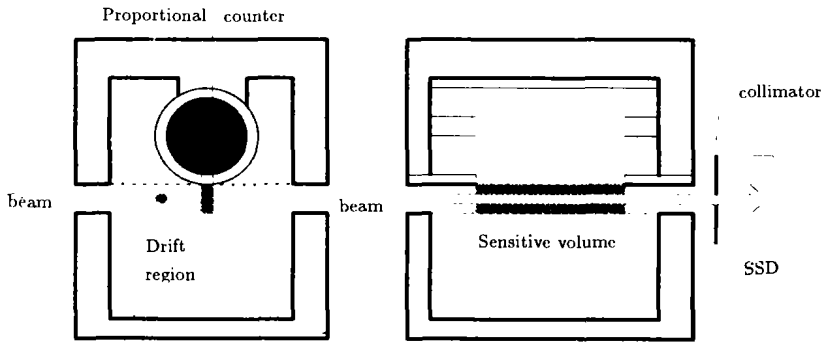

Fig.2 Transverse and longitudinal cross views of the detector

2.2 Three-dimension moving system

It is a plate that supports detector and can be moved 50 mm in X and Y directions with stepping motor, which has a screw of 2 mm pitch. One step of stepping motor is 1.5° that is equivalent to move 8.3μm in X and Y directions. It can assure that the simulation is at nanometre level. In Z direction, it can be easily moved 50 mm up and down to aim at the beam by hand.

2.3 Chamber

Because of the detector system worked in tissue-equivalent gas, the detector and three-dimension moving system must be put in a large chamber. The size of chamber is $\phi 600 \times 500$ mm with stainless steel. It is made up of gas inlet, pump, measurement pressured stable system interface, signal connecting plate, beam inlet and watching window. The beam goes through two collimators to ionization area, the first is made of Al of 5 mm thick and has a 3 mm aperture at center. Mylar film of 10μm thick used to isolate vacuum and air is sticked on the collimator, the second is made of Ta of 0.5 mm thick and has a 0.2 mm aperture at center.

2.4 Tissue-equivalent gas and stabling system

The measurement was performed in P-10 gas (0.90 volume fraction Ar and 0.10 volume fraction CH_4) with pressure of 645 Pa. It is equivalent to simulate 10 nm size in water. In measurement, it is important to maintain the gas to flow continuously at constant pressure through the detector. We used a type BALZERS stabilizing pressure system with a precise of better than 10 Pa.

2.5 Electronics

In order to minimize 'the electronic noise

an ORTEC charge pre-amplifier mode 142PC is used. The pulse from the counter anode is transfered via ORTEC mode 572 to 916 MCA system. The particle beam travels to the center of the drift region parallel to the slit and strikes a solid state detector, the signal of which forms a coincidence gate to open the 916 MAC system gate for the pulse of proportional counter.

3 Experimental principle

Experimental microdosimetry consists of the simulation of small tissue sizes, comparable to cellular and subcellular structures, by means of gas-filled cavities, and the detection of ionization distribution in the cavity by radiation. For a valid simulation, the energy loss of passing charged particles with equivalent trajectories must be identical in the tissue volume and the gas volume. Thus, $(S/\rho)_t d_t \rho_t = (S/\rho)_g d_g \rho_g$=the mean energy losses of the charged particle in tissue and gas for a simulation size d_t of tissue and a size d_g of gas with $d_g k_{tg}=d_t$. If the mass stopping powers (S/ρ) are independent of the densities (ρ), then $\rho_t = \rho_g/k_{tg}$. Therefore, the mean energy losses in both volumes are equal if choosing $\rho_g/\rho_t=k_{tg}$, the size ratio of the tissue and the gas, that is to say, $d_t\rho_t = d_g\rho_g$. The gas density $\rho_g = \frac{M}{V} = \frac{PM}{RT}$. Then, $d_t\rho_t = \frac{PM}{RT}d_g$. M is gas moldcule weight, P is gas pressure, T is absolute temperature, R is gas constant. M, T, R and d_g are constants to a detector system.

4 Result and discussion

The measurements were performed in P-10 gas at pressure of 645 Pa. The scaling factor in tissue is 1.54×10^{-2} nm·mm^{-1} at a pressure of 1 Pa and at 20°C for P-10 gas.

In all measurements, the PC cathode and the upper mesh were grounded. The PC anode voltage was biased positively. The voltage was 370 V at pressure of 645Pa, the protective electrode was 260 V, the down mesh voltage was -3 V and the trapped electrode was 4 V. The down mesh and the trapped electrode were insulated.

The heavy ions were 30 MeV/u ^{40}Ar produced by HIRFL. It went through 24μm Ni window and parallel plate ionization chamber with a 10μm Mylar film foiled gold, and a range shift 20μm Mylar film from vacuum tube to detector chamber.

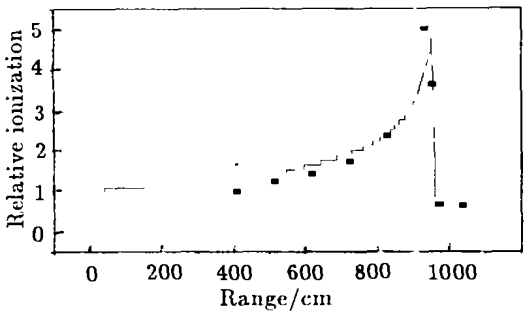

Fig.3 Calculated ( ) and measured (■) Bragg curves of 26 MeV/u ^{40}Ar in water

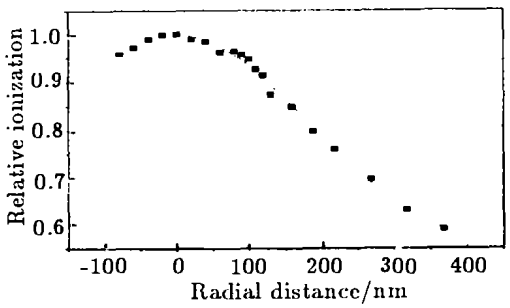

Fig.4 Relative ionization of 26 MeV/u ^{40}Ar in water

We obtained that the Bragg peak of 26 MeV/u ^{40}Ar ions degraded by 24μm Ni window is at 932 μm in water, it is comparable with 951μm, calculated by TRIM92 (see Fig.3).

It is of particularity to pursue the ionization distribution at Bragg peak in experiment, as shown in Fig.4. Fig.4 shows that the ionization distribution is Gaussian shape. These data provide the evidence that the wall-less counter is capable of measuring at nanometre level down to 10 nm.

References

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